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A SUMMARY OF THE OROGENIC EPOCHS IN THE GEOLOGIC HISTORY OF NORTH AMERICA

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INTRODUCTION

Ever since the appearance of Dana's *Manual of Geology*, students of American geology have been familiar with the idea that the earth's crust has from time to time suffered crumpling along sinuous belts, many of which have a suggestive parallelism to the margins of the ocean basins. Of these the folding of the rocks now underlying the Appalachian Mountains serves as an example and is undoubtedly one of the most widely known. Frequent notices of such epochs of deformation appear in later works by American geologists, and in recent years the general principle has been clearly stated by Chamberlin.[1] This principle, well supported by evidence from many points of view, is that the lithosphere is not an absolutely incompetent mass, but that it has sufficient powers of resistance to the forces which tend to deform it to be able to accumulate stresses for long periods of time without perceptible deformation. These periods of accumulation are periods of quiescence, during which base-leveling of the surface is widely extended.[1] Each period of quiescence and stress-accumulation is terminated by a short epoch of deformation during which the rocks yield to the overpowering stresses to such an extent as to produce temporary equilibrium among the stresses and thus inaugurate a new period of quiescence during which the cycle of planation of the surface may be repeated. Illustrations of the principle may be found in the history of any of the well-known mountain systems such as the Appalachians, the Rocky Mountains, or the Alps and their contemporaries.

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[1] T. C. Chamberlin, "Diastrophism the Ultimate Basis of Correlation," *Jour. Geol.*, XVII (1909), 685–93.

For the purposes of the present paper, the sharp foldings and often intense plications of strata are to be discriminated from those gentler but more widespread movements generally termed "warping." With the latter are often associated faulting of the so-called normal type, and volcanic activity. These things, although different in kind, are not unrelated. There is ample evidence that rock folding is often accompanied or followed by volcanic action; and one of the phenomena attending the plication along a narrow strip may be much more widespread warping with more or less normal faulting. Nevertheless, it is not clear that all four are necessarily present as phenomena of any one period of readjustment. In the strict etymological sense, folding, warping, faulting, and volcanic action are all "oro-genic" disturbances (*oros*="mountain," *gennao*="to produce"), since each may, independently of the others, give rise to mountain forms. In this paper, however, the word "orogenic" will be used in a somewhat limited sense and applied only to those epochs characterized by prominent rock folding.[2]

Recent textbooks and other general works on the geology of North America display an interesting lack of agreement as to the number of orogenic epochs recognized, in the emphasis placed upon them, and in the conscious discrimination between the crumplings and disturbances of other kinds. For example, Lyell[1] in 1855 makes no specific mention of such events; Dana[2] in 1875 enumerates seven more or less distinct epochs; Leconte[3] in 1891 gives four; Dana[4] again in 1895, eight more fully detailed than in 1875; Chamberlin and Salisbury[5] in 1905, six; Scott[6] in 1907, five; and Haug[7] in 1910–11, four (for North America). Dana was apparently among the first to see clearly that there had been a succession of foldings separated by periods of relative inactivity, and he early realized their importance as milestones in the progress of the earth's history. If all writers on the geology of local districts had even in recent years been as careful as Dana to distinguish between folding and mere change of level, or between folding, faulting, and volcanic activity, it would now be much easier for students of geologic history to interpret the local reports which necessarily form the basis of such general studies as this. We should not then be left in doubt as to just what an author means by the phrase, "a disturbance at the close of the Eocene" or "saecular changes in Acadia"; nor would the "Appalachian revolution" be described as extending from the close of the Mississippian to the end of the Trias and affecting most of North America.

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[1] As an additional but quite distinct factor in lowering the lands Chamberlin also introduces the idea of a slow glacier-like creep of the continental masses outward toward the ocean basins during the quiescent periods. Since planation and crumpling may alternate, whether body creep is a real process or otherwise, such a process will not be considered in this paper.

[2] The term "revolution" is often given to these disturbances but appears to be too strong a word, in view of the frequent recurrence of such events, the world over.

The following list (Table I) of orogenic epochs is compiled for the use of students of geologic history without any pretense of adding materially to the existing fund of knowledge upon the subject. Like codifications in general, it may serve quite as much to call attention to the existing lack of knowledge on many points, as to present what is already known. Each of the orogenic epochs deserves to be the subject of a special investigation, for the purpose of ascertaining more exactly the date and duration of the disturbance, its relations to those in other continents, the special

[1] Sir Charles Lyell, *Elements of Geology*, 5th ed.

[2] J. D. Dana, *Manual of Geology*, 2d ed.

[3] Jos. Leconte, *Elements of Geology*, 3d ed.

[4] *Op. cit.*, 4th ed.

[5] T. C. Chamberlin and R. D. Salisbury, *Geology*, Vols. II, III.

[6] W. B. Scott, *Introduction to Geology*, 2d ed.

[7] Émile Haug, *Traité de Geologie*, Vol. II.

TABLE I

Orogenic Epochs

Period	Division	Orogeny	Region Affected
Quaternary		<Santa Barbaran	California
Pliocene			
Miocene	Upper	<Antillean	Coast Ranges, Antilles, etc.
	Middle		
	Lower		
Oligocene			
Eocene	Upper		
	Middle		
	Lower		
(Paleocene)	Basal	<Laramide ? <Laramide	Rocky Mountain system
Cretaceous		<Oregonian	California, Oregon, etc.
Comanchean			
Jurassic	Upper	Nevadian	Sierra Nevada, Alaska Range, etc.
	Middle		
	Lower		
Triassic		<Appalachian	Appalachians to Newfoundland
Permian			
Pennsylvanian	Upper	<Arkansan	Southern Arkansas and Oklahoma
	Middle		
	Lower		
Mississippian			
Devonian	Upper	Brunswickian	Acadia to Central Virginia
	Middle		
	Lower		
Silurian		Taconic	Gulf of St. Lawrence to the Carolinas (?)
Ordovician	Upper		
	Middle		
	Lower		

TABLE I—*Continued*

Period	Division	Orogeny	Region Affected
Cambrian			
Algonkian	Keweenawan	<Penokean	South of Lake Superior (with extensions)
	U. Huronian		
	M. "	<Mesabian	North of Lake Superior (with extensions)
	L. "		
Archean		Laurentide ? ?	(Indefinite)

phenomena characteristic of it, and the distribution of the effects in varying degree.

THE INDIVIDUAL EPOCHS OF DEFORMATION

Laurentide orogeny (*late Archean*).—This may be included in our table more for the sake of completeness than because much information can be given concerning it. In the Lake Superior district, and particularly north of Lake Superior, the Archean rocks are generally more deformed and metamorphosed than the Algonkian strata which overlie them unconformably. In nearly all other districts where the Archean has been identified the same condition prevails. Whether these facts are to be interpreted as indicating a single almost universal orogenic disturbance just before the Algonkian deposits were laid down, or several, if not indeed many, such disturbances affecting successive strips of the continent at different times, is not now determinable. Considering the periodicity and local effects of the foldings in later geologic times, the latter view is perhaps the more favored one.

Mesabian orogeny (*late Middle Huronian*).—In northeastern Minnesota and adjacent portions of Canada the Upper Huronian (Animikean) strata lie gently tilted upon the contorted and partly metamorphosed beds of early Huronian and Archean age. The interval during which these folds were made and truncated has been termed the "Eparchean interval" by Lawson,[1] and by him

[1] A. C. Lawson, *Bull. Dept. of Geol. Univ. of Cal.*, III (1902), 51–62.

pronounced the most important stratigraphic break in the pre-Cambrian sequence. The emphasis thus placed on the mid-Huronian unconformity is due to the consideration of only a limited belt north of Lake Superior. When a much larger region is examined, this glorification of the mid-Huronian orogeny appears unwarranted. The nearly parallel relations of all the Huronian series south of Lake Superior proves that there the rocks were not folded in the mid-Algonkian. Recently Leith[1] has reviewed our knowledge of the mid-Huronian unconformity, showing that a conspicuous angular discordance between sedimentary beds of pre-Cambrian age has been found farther east in the Sudbury and Cobalt districts of Ontario, and on into Quebec. It is not certain that it is the same unconformity and that it is of mid-Huronian age in all of these localities, but it seems within the bounds of probability that such a correlation may be established in the future.

The lack of fossiliferous strata of the ages involved still prevents us from correlating the Algonkian sections of widely separated parts of the continent. Were it not for this fact, we might be able to ascertain in large measure the real extent of the Mesabian folding. Suggestively similar relations are found in the Rocky Mountains from Wyoming to Arizona, for in those states comparatively unaltered late Algonkian rocks rest upon highly contorted and metamorphosed sedimentary beds usually referred to the early Algonkian. The outcrops of these folds are largely covered by later strata and in isolated exposures the structural lines do not seem to follow a single general direction.

Penokean orogeny (late Algonkian=(?) post-Keweenawan).—Again the Lake Superior region supplies the standard of reference. After the extrusion of the Keweenawan basalts overlying the essentially undeformed Upper Huronian strata, the region immediately south of Lake Superior was compressed into folds trending nearly east and west. This apparently produced the Lake Superior synclinorium. In parts of northern Michigan the folding was intense, leaving the strata quite schistose and in nearly vertical attitude. Large batholitic intrusions accompanied the folding. On the north side of Lake Superior, however, the deformation was so mild that on the Mesabi Range and in Thunder Bay the Upper Huronian beds are still only gently inclined. Westward the Penokean orogenic disturbance can be traced with some confidence to the Cuyuna Range of central Minnesota, and southward perhaps as far as the Baraboo district of southern Wisconsin, where rocks usually referred to Middle or Upper Huronian are highly folded. Eastward it extended an unknown distance into Ontario.

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[1] *Proceedings of the Internat. Geol. Congress*, Toronto, 1913.

In reference to the late Algonkian orogeny, as to its predecessors, it is not yet possible to trace the extension of the folding much beyond the Lake Superior district because of the present uncertainty as to the ages of the strata. It is worth noting, however, that rocks believed to be of late Algonkian age, more or less strongly folded before the deposition of the Paleozoic beds, exist in the Black Hills of South Dakota, in Colorado, Montana, Utah, Arizona, and perhaps other western states and Canadian provinces. These beds are now so generally covered by younger rocks, that no continuous system of mountain folds has been worked out. The two Algonkian epochs of folding in the Rocky Mountains have been discussed by S. F. Emmons.[1]

Taconic orogeny (*late Ordovician*).—Because its effects are most evident in New England, the "Taconic revolution" was recognized more than fifty years ago by that group of geologists among whom Dana was ever a leader. Even today it would be difficult to improve upon the description, given in the early editions of Dana's *Manual of Geology*, of this signal event in the history of eastern United States. Because of its relation to fossiliferous strata, it is the first of the deformational epochs of which the age can be determined with a high degree of accuracy in the geologic scale and traced with confidence over a large area. Its effects in closely folded and even metamorphosed strata have been traced from the vicinity of Quebec (city) in Canada south through Vermont and western Massachusetts to New York City. Strong suggestions that it extended southwestward as far as Virginia have already been cited by Dana and others, but it is doubtful whether we shall soon know how far in that direction the crumpling was felt. The

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[1] S. F. Emmons, "Orographic Movements in the Rocky Mountains," *Bull. Geol. Soc. Am.*, I (1890), 245–86.

Cambro-Ordovician rocks were folded in the Gaspé Peninsula and as far as northwestern Newfoundland. The belt of deformation was apparently wide enough to include most of New Brunswick, perhaps Nova Scotia, nearly all of Maine, and probably even Rhode Island. The warpings and changes of level which accompanied the folding affected a large part of the eastern interior of the United States and doubtless Canada. These movements have lately been summarized by Schuchert.[1] In western United States, however, there appears to be evidence of nothing more than a change of relative altitude between the sea-level and the land surface.

Brunswickian (late-middle Devonian).—Although the folding of the older rocks in eastern Canada, just before the deposition of the Carboniferous measures, was well known to Logan, Dawson, and other pioneer Canadian geologists, and is noted by Dana in all the editions of his *Manual*, the event has received much less attention than it deserves from geologists in general. Several of the more recent textbooks of geology make no mention of the occurrence, and it is sometimes ignored in discussions of Devonian paleogeography where it is a factor of importance. Dawson's description,[2] although reflecting some provincial bias, may serve to call attention once more to the importance of the Devonian disturbance. He says in part:

> The whole surface of Acadia was thrown into a series of abrupt folds—great masses of plastic granitic matter invading every opening in the shattered masses. This period surpasses every other, in the geological history of the eastern slope of the American continent, in its evidence of fracture of the earth's crust. To this period we must refer the greater part of the intrusive granites of Eastern America, and to it also is referable the greater part of the metamorphism of the Silurian rocks, and the origin of the numerous metallic veins by which these are traversed.

As there appears to be in current use no name for this folding, the term "Brunswickian" is suggested to meet the evident need.

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[1] Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. Am.*, XX (1908), 488–89.

[2] Sir William Dawson, *Geology of Nova Scotia, New Brunswick, and Prince Edward Island*, 2d ed. (1891), pp. 665–66.

The tract within which the rocks were crumpled during this epoch stretches from western Newfoundland through Cape Breton Island, Nova Scotia, New Brunswick, Maine, and probably southern New England, and was wide enough to include on the northwest the Gaspé Peninsula in eastern Quebec. Farther southwestward, the evidence becomes scanty, but the marked unconformity beneath the basal Carboniferous beds near Boston and in Rhode Island suggests that it extended at least as far as Long Island Sound. Willis[1] has shown that the great thickness of late Devonian and early Carboniferous clastic rocks in Maryland and Virginia strongly suggests the rise of mountain ranges immediately to the east, in the region now occupied by New Jersey and eastern Virginia. Using the same criterion, the dwindling and eventual disappearance of such formations between Virginia and Alabama suggest that the folding did not extend the entire length of the present Appalachian Mountain belt.

Although there are some discrepancies in the evidence and hence some disagreement among writers on the subject, the testimony of unconformities on the one hand, and of thick clastic formations on the other, indicates that the Brunswickian disturbance culminated after the middle of the Devonian but considerably before the close. In Acadia the folds had been truncated before the Lower Carboniferous (Mississippian) period and beds of that age were deposited upon the eroded stubs.

Arkansan (mid-Pennsylvanian).—The folded structures underlying the mountains of Arkansas and Oklahoma were made, as nearly as can be inferred from current correlations, in the latter part of the Pennsylvanian period. Thus in the central Arkansas coal field the deformation followed the laying-down of the lower Pennsylvanian coal measures,[2] but no younger strata exist there. In the Arbuckle Mountains of Oklahoma it occurred after the deposition of the Caney shale (early Pennsylvanian ?) and before that of the Franks conglomerate (late Pennsylvanian). In the Wichita Mountains still farther west in the same state, the folds had been truncated before the deposition of the Oklahomian (early

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[1] Bailey Willis, *Geol. of Maryland*, IV (1902), 23–93.

[2] A. J. Collier, "Coal Fields of Arkansas," *U.S. Geol. Survey, Bull. 326*, p. 24.

Permian) red beds. Thus it is the conclusion of Taff[1] "that the Arbuckle uplift [= crumpling] began near the middle and culminated near the close of Pennsylvanian time, previous to the deposition of the red beds."

The folds are sharply compressed and cut by overthrusts and other faults as in the Appalachians, but there are no contemporaneous igneous intrusions and the rocks were not much metamorphosed. In Oklahoma, the Arkansan system of folds trends east by south, but the strike becomes more nearly east and west in Arkansas. Extensions of the system in the line of strike are unknown, because both to the west and to the east the folded beds are concealed by overlapping horizontal strata of later age. The same is true to the south. Southwestward in the Llano[2] district of central Texas, early Pennsylvanian strata are the youngest involved in the very mild folding and faulting which the stratified rocks now show. Their deformation may perhaps be related to the Arkansan disturbance. North of the Arkansas River the Carboniferous strata still lie almost horizontal, and in Kansas there is not so much as a disconformity between the early and later Pennsylvanian strata. In the Ozark region of Missouri and northern Arkansas the very gentle flexures and normal faults may possibly be referable to this epoch, but as yet the evidence is of little weight. Slight deformation of the Mississippian and older strata along the Mississippi River in Illinois, Iowa, and Missouri, and the making of the LaSalle anticline of Illinois seem to have in large measure preceded the Pennsylvanian, and if so, are not to be correlated with the Arkansan orogeny. The disturbance seems too slight to include, in the present list, as a distinct orogeny.

The folding of the Ouachita beds has been referred by Dana and others to the Appalachian revolution. However, unless published correlations are seriously in error we must conclude that the Ouachita folds had been formed and truncated before the deposition of the latest Pennsylvanian sediments, whereas the Appalachian folds were not begun until after the early Permian strata had been laid down. It is now generally agreed that the climax of that disturbance came near the close of the Permian period. If these correlations are correct, we must then recognize two separate orogenic epochs. There is apparently ground for correlating the Arkansan crumpling with that which produced the Armorican and Variscian systems of western Europe, which Haug[1] assigns to the opening of the Stephanian (upper Pennsylvanian) epoch.

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[1] J. A. Taff, "Geology of the Arbuckle and Wichita Mountains," *U.S. Geol. Survey, Prof. Paper 31*, p. 80.

[2] Sidney Paige, *U.S. Geol. Survey, Llano Folio, No. 183*, Texas.

Appalachian orogeny (*late Permian*).—This epoch of folding was the first to be well recognized in America and is without doubt the one now best known to students of American geology. Its effects have been traced from Alabama to New York and from southern New England to Newfoundland. The southeast limit of the area affected is everywhere concealed either by the ocean or by much younger undeformed deposits. To the northwest the limit is rather sharply defined where the folds give way to the horizontal strata of the Cumberland and Alleghany plateaus. There are, it is true, some broad gentle swells in these apparently horizontal beds, and those flexures were probably produced at the same time as the Appalachian folds. In western New England and adjacent parts of New York and Canada, the limits are less easily ascertained because little now remains but pre-Devonian or even pre-Silurian strata, and those had been already folded either in the Brunswickian or the Taconic epoch or both. Available evidence, although meager, indicates that the crumpling and overthrusting at the close of the Permian were even more intense in the Piedmont and New England regions than in the Appalachian Mountains themselves.

Reasons have been given above for believing that the Ouachita region was not deformed at this time. If this conclusion is correct it may be said that the western three-quarters of North America was not affected by the Appalachian orogeny except that there were, over large areas, mild epeirogenic movements which made notable changes in the relations of land-masses and seas.

Nevadian (*late Jurassic*).—The folding of the rocks in the Sierra Nevada at the close of the Jurassic was established by Whitney and his associates about half a century ago, but it seems to be less widely understood that the entire west coast of North,

[1] Émile Haug, *Traité de Geologie*, II, Part I (1910), p. 829.

and probably South, America was affected at about the same time. Smith[1] has called this the "Cordilleran revolution," but since it affected less than half of the great mountain tract of the West, to which we usually apply the name "Cordilleras," the designation seems likely to mislead and will perhaps tend to perpetuate a widespread popular misconception of the western mountains as all belonging to one great system instead of two or three systems. The term "Nevadian" has therefore been substituted in this paper, in allusion to the Sierra Nevada.

The system of folds made at this time trends in a north-northwesterly direction more or less parallel to the Pacific shore of today, but by no means coinciding with it. South of the typical area in the Sierra Nevada, the Jurassic folds may be traced into western Mexico and probably Lower California. Northward along the strike it may be traced through Oregon, the Cascade and Olympic ranges of Washington, the Coast Range of British Columbia, and the St. Elias and Alaskan ranges beyond. There are even suggestions of its extension into the Aleutian chain. Its western limit is concealed everywhere by the Pacific Ocean or by unconformably overlapping younger deposits which have themselves been folded subsequently. To the east and northeast, the Nevadian system of folds is involved with the overlapping Laramide system and it therefore becomes a difficult task to discriminate the two. The eastern limit of the Nevadian folds seems to be reached approximately near Bisbee, Arizona, where Comanchean sediments overlie unconformably the deformed Paleozoic strata, and the ill-defined boundary may be traced northwestward through eastern Nevada,[2] western Idaho, central British Columbia, the upper Yukon valley in Canada, and central Alaska in general. There is good evidence that it did not affect Alaska north of the Yukon nor the eastern ranges of Mexico.

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[1] J. Perrin Smith, *Science*, XXX, 346–51.

[2] It should be noted that much of this region has been so modified by igneous intrusions and faulting of much younger date that the results of the Nevadian orogeny have been in large measure lost to view. It is these later disturbances which have made the present Basin Range province of Nevada distinct from the Sierra Nevada province of California, though both were once parts of the Jurassic belt of folding.

Throughout this great belt, which doubtless has extensions in Asia on the west and also in South America, the folding was accompanied or followed by the intrusion of enormous masses of granitic rocks, the commonest types among which are granodiorite and quartz-diorite. In the intensity of the folding there was much variation, but through California and Washington, at least, it was great.

Although nearly all writers on the subject agree in assigning this epoch of diastrophism to the Jurassic period or its close, there is considerable difference of opinion as to a more precise date. The Alaskan geologists have usually referred it to the middle Jurassic. Stanton and the earlier Californian geologists assigned it to the end of the Jurassic. According to J. P. Smith it took place just before the Portlandian epoch of the late Jurassic. These differences of opinion are probably in large part due to the difficulty of correlating the faunas of such widely separated countries as California, Alaska, and Europe, rather than to any real difference in the date of the disturbances in the several regions.

Oregonian orogeny (*post-Comanchean*).—In the literature of Pacific coast geology there is much evidence to indicate that the deposition of the Shasta and related series (Comanchean) was followed by crumpling of the strata, accompanied by the intrusion of igneous rocks, especially peridotitic varieties, now changed to serpentine. The phenomena have been found interruptedly from southern Mexico through California, Oregon, and Washington to southeastern Alaska. In all cases they lie near the coast, and in no instance are they known to occur east of the area affected by the Nevadian orogeny. As in that preceding orogenic epoch, so here, the folds appear to be roughly although not exactly parallel to the edge of the Pacific basin. In most districts the folding was of moderate intensity but in southwestern Oregon the Comanchean strata stand on edge in isoclinal attitude.

All inferences as to a period of deformation between the lower and the upper Cretaceous necessarily rest upon the correlations of the strata involved. On the whole, the Comanchean and Cretaceous beds of the Pacific province are only sparingly fossiliferous and many of the species, such as *Aucella*, are of large vertical range and hence of doubtful value in correlation. The various writers on Pacific coast geology are, therefore, by no means in harmony as to the ages of some of the strata. The existence of a conspicuous angular unconformity is conceded. Above this conformity lies either the Chico (upper Cretaceous) or certain Eocene formations. Below it lie much more highly folded and locally even metamorphosed rocks which may in general be referred to as the *Aucella* beds. These have yielded both invertebrates and plant remains. The former have been classified usually as lower Cretaceous, but sometimes as late Jurassic; the plants nearly always as Jurassic. At present the balance of qualified opinion seems to be in favor of regarding the system as largely Comanchean but in part late Jurassic. This orogeny, if it was a fact, is among the least-known in the later part of the earth's history.

Laramide orogeny (*post-Cretaceous*).—The deformative movement which gave birth to the Rocky Mountain system is one of the three best-known events of its kind in North America. The folds thus produced trend north by west from southeastern Mexico to western Texas, thence across New Mexico, Colorado, Wyoming, Montana, western Alberta, and the northwest provinces of Canada into northern Alaska, finally reaching the Arctic Ocean at Cape Lisburne. Although there may have been folding in Central America also at this time, the fact that the same region suffered a further crumpling in the midst of the Tertiary has largely if not entirely obliterated evidences of earlier deformation there. The post-Cretaceous folds reappear, however, in full force in the Andean system of South America. On the eastern or inland side of the system the limits are generally distinct, for the folds pass somewhat abruptly into the nearly horizontal strata of the Great Plains. There are, however, some outlying tracts of disturbance characterized by gently tilted strata and laccolithic intrusions, as in the Black Hills of South Dakota and the Uvalde district of Texas. The same general condition seems to prevail throughout the extent of the system. On the westward or Pacific side the limits are much less definite because the post-Cretaceous folds are not easily distinguished from those of the Nevadian epoch, except where late Cretaceous strata are present; and it is an embarrassing fact that outcrops of rocks of this age are comparatively scarce in the plateau region between the Pacific and Rocky Mountain systems. Such facts as are now available suggest that the western limit of the Laramide disturbance passes through central Arizona, eastern Nevada, western Idaho, and central British Columbia to the Yukon valley. This tentative division of the provinces is supported by the fact that the Comanchean rocks in the Bisbee region, Arizona, have been gently tilted and faulted but only slightly folded; the Cretaceous rocks near the headwaters of the Yukon River have been folded, and the same is true of beds of similar age on the northeast side of the Seward Peninsula in Alaska. On the other hand, along the Pacific slope in California, Oregon, Washington, British Columbia, and Alaska, wherever both upper Cretaceous and Eocene strata are present, they are generally either conformable, or separated by a mere disconformity. At the north end of the Sacramento Valley, California, the upper Cretaceous strata still remain almost horizontal.

There is substantial agreement among geologists that the Laramide orogeny marks approximately the close of the Cretaceous period. Nevertheless, until the existing controversy over the correlation of the latest Cretaceous and earliest Eocene formations of western United States is satisfactorily settled, the exact date of the deformation remains uncertain. In some parts of western Wyoming and Colorado there are suggestions of two episodes of crumpling separated by a short but definite epoch of erosion and the deposition of sediments in the earliest Eocene (Paleocene). Similar phenomena are reported from Yellowstone Park and southwestern Montana.

Throughout its range the Laramide orogeny was marked by great volcanic activity, which manifested itself in the production of laccoliths and volcanic cones with their associated dikes, sills, flows, and fragmental deposits. Locally in parts of Idaho and western Montana granitic batholiths were intruded at this time, but they are much less characteristic of the Laramide system than of the Nevadian.

Antillean orogeny (*middle-to-late Miocene*).—It has long been known that the dominant structural features of the California and Oregon coast ranges were produced in the Miocene period. To the north the deformation may be traced through the Oregon Coast Range to the Olympic Mountains of Washington, thence through the coastal islands of British Columbia, to the southern Alaska coast, and on into the Aleutian chain. To the south the same deformation is reflected in the tilted and more or less disturbed Eocene beds of Lower California. Beginning in southwestern Mexico, a belt of complexly folded and faulted rocks with volcanoes extends through Honduras and other Central American states, through the West Indian islands to Venezuela. These folds involve Eocene, Oligocene, and even Miocene strata, but are unconformably overlapped by the undisturbed Pliocene. Eastward and northward the effects of the Antillean disturbance wane into gentle folds and finally into mere warping, accompanied by normal faults and volcanic structures. Decided folding of early Tertiary strata extends as far east as southwestern Nevada, the Blue Mountains of Oregon, the Cascade Range and Okanagan regions of Washington, at least the western part of the Fraser River basin of British Columbia, and the upper Yukon valley. In Alaska it affected the Kuskokwim Mountains and Nunivak Island, but not the Mt. Wrangell district or the region north of the Yukon River. Even as far east as the Rocky Mountain states of Wyoming, Colorado, and Montana, the Eocene and Oligocene strata are locally somewhat tilted and broken by normal faults, suggesting that the Antillean disturbance made itself felt in a mild way as far east as the edge of the Great Plains. Eastern United States suffered no folding but there was some warping, especially in Florida and the Gulf states.

By comparison with the Nevadian and Laramide disturbances, it will be seen that the Antillean orogeny affected an area as large as, or even larger than, the Nevadian, and again the strongest folding is found nearest the Pacific coast. Almost throughout the range of the Miocene disturbance, whether mild or severe, volcanoes broke forth and scattered their lavas and fragmental deposits far and wide. In that respect the epoch may have exceeded even the Laramide orogeny. Batholiths of the Antillean epoch are reported from the Cascade Mountains of Washington and British Columbia; they are probably the youngest known.

Nearly all authorities agree in assigning this event to the middle Tertiary, and by many it is referred to the close of the Miocene period. In the John Day basin of central Oregon, according to Merriam and Sinclair,[1] gentle folding closed the deposition of the early Miocene sediments, and preceded the Columbia lava outflows. In the northern part of the Cascade Mountains of Washington a similar event is recorded by Smith and Calkins.[2] The most accurate estimate of the date of the deformation seems to be that which has been made in the Coast Range of southern California by Arnold[3] and others, who show that it followed the deposition of the lower-middle Miocene sediments (Monterey shale), and preceded that of the upper Miocene (Santa Margarita).

Santa Barbaran orogeny (*early Pleistocene*).—Recent studies in the oil-bearing districts of southern California have brought to light the fact that, although the region was considerably affected by the Antillean orogeny, it was as much or even more closely compressed after the deposition of the marine Pliocene formations. Thus in the region about Santa Barbara, the Pliocene has been not only folded but overturned, and locally lies beneath overthrust masses of earlier Tertiary strata. In the Coalinga oil district[4] on the southwest side of the great valley of California, the effects of the Santa Barbaran disturbance are much more pronounced than those of the middle Miocene folding.

Although it has long been known that warping, gentle changes of level, and normal faulting proceeded on a large scale early in the Pleistocene period, particularly in western United States, there are but few places outside of California where actual folding has been assigned to this age. Possibly we should refer to the Santa Barbaran folding the gentle flexures in the late Miocene lavas of central Washington and the Cascade Mountains, as well as the latest gentle folds in the Olympic Range of the same state. To the north the comparative scarcity of Pliocene strata renders the tracing of the folding in that direction more difficult. In the region of the Antilles, Pliocene strata are much more abundant, but there they are apparently not folded and only very gently tilted.

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[1] J. C. Merriam and W. J. Sinclair, *Bull. Dept. of Geol. Univ. of Cal.*, V (1907), 174.

[2] G. O. Smith and F. C. Calkins, *U.S. Geol. Survey, Snoqualmie, Wash., Folio, No. 139.*

[3] Ralph Arnold, "Environment of the Tertiary Faunas of the Pacific Coast of the United States," *Jour. Geol.*, XVII (1909), 509–33.

[4] *Ibid.*, "Geology of the Summerland Oil District, California," *U.S. Geol. Survey, Bull. 321.*

GENERAL CONSIDERATIONS

The table of orogenic epochs given above is still far from complete, and tabulations of this kind are necessarily subject to correction. The most evident defects relate to the pre-Cambrian. Until the pre-Cambrian terranes in widely separated districts have been correlated much more securely than at present, we shall not know how many orogenic epochs fell within the Archeozoic or even the Proterozoic era; and we shall know but little of the true extent of those ancient orogenies which are already recognized as facts. Again, the effects of some orogenic movements, especially near the borders of the continent, have been so masked by later crumplings or have been so largely buried beneath younger sediments or by the sea itself, that the record, once clear, is now largely destroyed. Thus we know nothing of the southwestward extension of the Appalachian system of folds beneath the sediments of the Gulf coastal plain; and on the Pacific slope the complex structure and metamorphism render it difficult to get information about any orogenic epochs which that region may have suffered before the Jurassic. Some of these limitations will gradually be removed as the making of critical local studies progresses.

In most of the known epochs of orogeny, a single elongate belt was affected, while much broader surrounding regions experienced nothing more revolutionary than changes of level, gentle warping, a little faulting, and sometimes volcanic activity. Most of the folded belts were thousands of miles in length and a few of the best-known measured many thousands. The Laramide system of the Americas extended over about half of the earth's circumference, and the Miocene folded belts are long enough to reach more than one and a third times around the globe.

The belts vary from 50 to more than 600 miles in width and in Asia locally exceed 1,000 miles. The average width of the crumpled zones is, however, between 100 and 300 miles. Where the folding is closest, the zone is likely to be narrower than where the folds are open and wavelike. If this is generally true, it may mean that the narrowest places are narrow because they have been the most compressed.

The crumpled strips produced at each epoch overlap more or less, but rarely coincide. Thus the Mesabian orogeny affected the north side of Lake Superior while the Penokean affected the south side. Again, the Laramide and Nevadian zones are largely distinct, although they overlap considerably. Successive foldings in the same general region were usually roughly parallel to each other and resulted in an ever-widening belt of crumpled strata. In North America we have at least three such composite zones, the Cordilleras in the west, the Atlantic system in the east, and the ancient systems of the Canadian shield where nearly all structures trend east by north.

Although overlapping of the limits is common, it is rare that the locus of greatest intensity occurred twice in the same place. The Sierra Nevada region, intensely folded in the Jurassic, was but little affected in the Miocene, although the Coast Range to the west and parts of Nevada to the east both suffered folding at that time. Intense crumpling produces a thickening of the deformed strip and therefore increases its competency to resist further thrusts and to transmit them to regions beyond. It seems probable, also, that the intrusion of great batholiths such as accompanied the Nevadian orogeny must notably strengthen the mass within which they congeal, and thus render it less liable to yield to compression in later periods.

Many students of the subject have shown that some of the disturbances were inter-continental. For example, there appears to have been some crumpling in northwestern Europe, corresponding approximately in time to the Taconic orogeny in eastern North America. The Brunswickian likewise has its counterpart in the mid-Devonian deformation in Scotland. The Arkansan seems to correspond in time to the Armorican orogeny of western Europe, the Nevadian to the folding of the eastern interior ranges of Asia, and the Antillean almost unquestionably to the rearing of the great Alpine system of Eurasia. These striking correspondences strongly suggest that the orogenic forces are not local but planetary. Chamberlin[1] regards the crumplings on two sides of an ocean as a result of the subsidence of the earth segment beneath that ocean.

The folding along the relatively narrow belts was nearly always accompanied by more or less warping and volcanic activity over adjacent, much wider areas. The warpings have not infrequently disturbed stream activities and strand-lines over large portions of continents, as at the close of the Permian and in the Miocene. The transitions from the folded to the merely warped areas are in some cases abrupt and in others gradual, through gently folded or faulted tracts. Where the demarcation is sharp, as the east side of the Rocky Mountains, there may have been some original line of weakness such as a decisive initial dip; whereas in the cases of gradual transition the underlying mass may be tolerably uniform in resistance, and may therefore permit the force to be transmitted through it and die away gradually.

In several instances observed relations indicate that the most effective compression was accomplished on the side toward the ocean basins. Thus we have the closely appressed folds and overthrusts of the Laramide system in western Montana and Idaho changing into gentle open folds farther east. Again, in the Appalachian orogeny, the Rhode Island district was more closely crumpled and metamorphosed than Pennsylvania on the northwest side of the deformed zone; and a like comparison may be made between the region of great overthrusts and isoclinal folds in North Carolina on the southeast and the open arches of northern Alabama on the northwest. For at least some of the orogenic systems there seems to be a significant arrangement of the batholithic intrusions on the seaward side of the zone, with superficial volcanoes and laccoliths along the landward side. This is perhaps only another way of saying that the batholiths are characteristic of the more intensely folded parts of the zone, while the superficial volcanic features occur where the rocks have been less deformed. It is admitted, however, that this distribution of intensities and phases of igneous activity cannot be demonstrated for many of the epochs and may be accidental rather than significant.

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[1] T. C. Chamberlin and R. D. Salisbury, *Geology*, I (1904).

There is a conception familiar to present-day geologists, that the great mountain systems coincide with geosynclinal depressions in which sediments have previously accumulated to unusual thicknesses. The Appalachians have served as a classic example. In the opinion of some, the trough was deepened by lateral pressure and the deposition of the sediments thus invited. The extreme isostasists, on the other hand, view the trough as a result of the loading of the strip by the deposition of thick sedimentary beds. Willis urged the importance of the initial dips developed in these geosynclines in predetermining the locus of the folded belt when the compressive force became effective. It is prudent, however, not to assume that there is a causal relationship between belts of thick sediments and subsequent mountain folding, merely because one preceded the other. Much of the thickness of the Appalachian sediments was directly due to the ruggedness of the land-mass of Appalachia, from time to time in the Paleozoic era; and it should be recalled that at the close of the Permian not only the Appalachian geosyncline, but a still broader region to the east, was intensely deformed. The observed relations may be stated in another way, namely, that sediments accumulate rapidly along mountainous coasts, and that coasts in turn are liable to repeated crumplings, for reasons not here discussed. Hence the two phenomena are generally associated.

In each great portion of the continent there have been successive roughly parallel crumplings, separated by long periods of quiescence, and, in some cases at least, eventually terminated by a cessation of activity which has endured down to present times without premonition of change. In the Lake Superior region, three, and probably many more orogenies, were passed before the Cambrian, but in all subsequent time there have been none. In the Atlantic mountain system three or more crumplings before the Triassic have been followed by a stability prolonged until the present, and with no suggestions of an end. In the western Cordilleras the orogenic activities seem to have slumbered until the Jurassic, but since then the region has been subjected to repeated compressions and is the one in which future disturbances are most likely to take place.

When the earlier and later orogenic epochs are compared, there appears a suggestive sameness running through the whole series. Although we are still unable to express geologic chronology in terms of years, an estimate expressed in terms of epochs or thickness of strata suggests that the crumplings were no more frequent in the Paleozoic era than in later periods; nor do the facts seem to imply that the earlier disturbances were more intense or more widespread. In fact, if we should take the available data without making allowance for the greater loss of record pertaining to the earlier periods, we might reach the improbable conclusion that they had been more widespread, more severe, and more numerous since the Triassic than before.

THE CAUSES OF OROGENIC EPOCHS

It is beyond the purpose of this paper to discuss the origin of earth folding.

From the very nature of its effects, the cause of orogenic epochs must be sought in tangential compression affecting the rocks of the earth's outer shell. As to the origin of that force there is, however, no unanimity. It constitutes a problem for which several hypotheses have been offered. These are explained and critically analyzed in the writings of Dana,[1] Reade,[2] Chamberlin,[3] Willis,[4] Taylor,[5] Leith,[6] and others.

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[1] J. D. Dana, *Manual of Geology*, 4th ed. (1895).

[2] T. Mellard Reade, *Origin of Mountain Ranges*, p. 125.

[3] T. C. Chamberlin and R. D. Salisbury, *Geology*, I (1905).

[4] Bailey Willis, "Research in China," *Carnegie Institution*, II (1907).

[5] F. B. Taylor, "Origin of the Earth's Plan," *Bull. Geol. Soc. Am.*, XXI (1910).

[6] C. K. Leith, *Structural Geology* (1913).